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TECHNICAL MEMORANDUM

LACIE TRANSITION YEAR PLAN FOR THE DIRECT ESTIMATION OF WHEAT FROM LANDSAT IMAGERY

By

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16. Abstract <p>This research plan describes the evaluation of existing technology and the development of new and improved procedures for the direct estimation of spring wheat area in the Large Area Crop Inventory Experiment (LACIE). An experimental procedure for directly estimating spring wheat area that was implemented during LACIE Phase III is evaluated in terms of its accuracy and transferability. In addition, plans for an integrated Classification and Mensuration Subsystem (CAMS) and Research, Test, Evaluation (RT&E) research program are described. This research program will focus on the fundamental spectral separability of spring wheat from other spring small grains. A variety of displays of Kauth-transformed data values and time variables will also be considered. The On-Line Pattern Analysis and Recognition System (OLPARS) will be used to investigate separability as a function of crop calendar and multitemporal separability. In addition, several types of fixed and segment-dependent projections will be examined for possible use as analyst labeling aids.</p>					
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ABBREVIATIONS

CAMS	Classification and Mensuration Subsystem
CEF	Classification and Mensuration Subsystem Evaluation Form
LACIE	Large Area Crop Inventory Experiment
LIST	List Identification from Statistical Tabulation
NASA	National Aeronautics and Space Administration
OLPARS	On-Line Pattern Analysis and Recognition System
PCC	Probability of correct classification
PDP 11/45	Programmed Data Processor, model 11/45
Pixel	Picture element
RT&E	Research, Test, and Evaluation

I. INTRODUCTION

During the 3 years that the Large Area Crop Inventory Experiment (LACIE) has been operational, it has become apparent that spring wheat must be distinguished from other spring small grains such as barley, flax, and oats in order to obtain an accurate wheat area estimate. Because the spring small grain crops are so similar in their reflectance and development patterns, the analyst-interpreters have not been able to identify and label all of the separate spring small grain signatures with the same confidence with which they can label small grains as a group. Thus, the practice in LACIE has been simply to label and classify spring small grains as a class and, then, to generate a wheat estimate using a ratio of wheat to other spring small grains based on historical and economic variables. Such ratios are developed separately for each-stratum.

The wheat ratios are not constant from year to year and are difficult to predict accurately. Therefore, a LACIE Transition Year goal is to reduce the dependence of the spring wheat estimates on the historical ratios of spring wheat to spring small grains and other confusion crops by estimating the proportion of spring wheat directly from the Landsat imagery.

Prior to LACIE Phase III, a procedure was developed utilizing the ground-truth data for 10 Phase II North Dakota blind sites. During Phase III, this procedure was used experimentally in the operational processing of the North Dakota sample segments.

This plan describes the evaluation of the existing technology and the development of new and improved procedures for the direct estimation of spring wheat for application in the LACIE Transition Year.

2. APPROACH

Three activities will be conducted to support the LACIE initiation of the direct estimation of wheat in the LACIE Transition Year. First, the application of the direct wheat estimation procedure to North Dakota in Phase III will be evaluated. Second, the direct wheat estimation procedure will be checked for transferability to the mixed grain states and to another year. Third, Research, Test, and Evaluation (RT&E) and Classification and Mensuration Subsystem (CAMS) design personnel will proceed with separate but coordinated research efforts in direct wheat estimation. An effort will also be made to determine the importance of 9-day coverage and to monitor the research by other organizations which relates to the direct wheat estimation procedure.

2.1 EVALUATION OF THE PHASE III NORTH DAKOTA DIRECT WHEAT ESTIMATION PROCEDURE

A direct wheat estimation procedure was used operationally in North Dakota during Phase III. (The procedure and the guidelines upon which it was based are presented in appendix A.) Ground-truth data were collected on 28 of the sample segments allocated within the state. Some of these 28 blind sites were never processed because of insufficient acquisitions, others were not able to pass the criteria for a satisfactory estimate, and still others had a very low percentage of small grains within the scene.¹ These factors combined to reduce the number of blind sites available for evaluation to 21. An additional three segments were deleted because Accuracy Assessment could not provide ground-truth tapes for segments with more than 500 fields. For each of the 18 remaining blind sites, summary statistics are being calculated and recorded. These statistics will be used to evaluate the procedure. Hopefully, they will be sufficient to answer the following questions:

- a. How accurately were the analysts able to label spring wheat dots?
- b. How accurately were the analysts able to label spring wheat dots which were classified as small grains?

¹The direct wheat estimation procedure applied in Phase III is not applicable to segments with a low density of small grains.

- c. Are the accuracies obtained for discriminating wheat from other small grains by this procedure greater than those obtained from random chance?
- d. How accurately was the machine able to classify the 209 dots?
- e. The direct wheat estimation procedure assumes that the ratio of wheat to small grains is the same for those picture elements (pixels) classified as small grains as it is for those pixels classified as nonsmall grains. To what extent is this assumption tenable?
- f. How well do the LACIE wheat proportion estimates agree with the ground-truth wheat proportions?

The forms upon which the data are to be recorded are presented in appendix B. The forms for the tabulations are in appendix C. These show in detail the terms to be quantified and the statistics to be generated.

2.2 TRANSFERABILITY OF THE DIRECT WHEAT ESTIMATION PROCEDURE

The direct wheat estimation procedure developed with North Dakota Phase II blind sites was tested on North Dakota Phase III blind sites and is proposed for use on the LACIE Transition Year sites in the spring grain and mixed grain² states of Minnesota, Montana, North Dakota, and South Dakota. Prior to the implementation of a direct wheat estimation procedure in LACIE operations for the Transition Year, two considerations for transferability will be addressed: (1) Is the procedure transferable to the other spring grain and mixed grain states? (2) Is the procedure transferable to another year? In order to answer these questions, the plots for the Phase III North Dakota direct wheat estimation procedure will be reproduced by examining data from the Phase III blind sites in the four spring grain and mixed grain states (appendix A). An intensive analysis of these plots will be conducted to determine which of the proposed characteristics of separation (guidelines) of the spring grains are consistent from year to year and state to state. Although somewhat subjective, these evaluations should provide some insight into the applicability of the procedure or a modified version of the procedure.

²Mixed grain contains both spring and winter grain.

To begin this analysis, the collection of ground-truth data for the 209 dots must be completed for the blind sites in the other mixed grain states. Since the rate of flow of acceptable ground-truth data from Accuracy Assessment will not be sufficient to support this effort as scheduled, analysts are obtaining these data manually from ground-truth overlays of the aircraft photography.

2.3 CAMS PROCEDURE DEVELOPMENT

The improved direct wheat estimation procedure to be implemented in the Transition Year of LACIE will be developed in three basic parts. Part 1 will consist of scrutinizing the data collected and prepared for the Phase III evaluation (section 2.1) and the transferability study (section 2.2) to screen out all instances where separability is apparent. The different plots to be examined are presented in appendix D. In part 2, all the facts surrounding the instances of separability will be examined to determine when, under what conditions, and how consistently they occur. The results of parts 1 and 2 will be conveyed to RT&E for interfacing with their research (section 2.4). During and after parts 1 and 2, the results from the RT&E activities will be reviewed. In part 3, all the research results will be collected together, and a search for a procedure which takes advantage of the newly found knowledge will be conducted.

2.4 RT&E DIRECT WHEAT ESTIMATION RESEARCH

In the direct wheat estimation research, RT&E will approach the problem using techniques and software that differ from those being used in CAMS. Time variables, raw data values, and Kauth-transformed data values essentially comprise the CAMS developmental elements, whereas RT&E will utilize a software package which permits more flexible data manipulation. This effort will rely upon the data collection and results of the LACIE Phase III evaluation, the transferability study, and parts 1 and 2 of the CAMS procedure development activities.

The potential benefit from the RT&E direct wheat estimation research will be a better presentation of the data than is currently available. In addition, the

latest research from outside organizations will be monitored for its relevance to this activity and integrated when appropriate.

2.4.1 ON-LINE PATTERN ANALYSIS AND RECOGNITION SYSTEM

The primary tool to be used in this research is the On-Line Pattern Analysis and Recognition System (OLPARS), developed at the Rome Air Development Center, Rome, New York, and resident there on a Honeywell 6180 computer. The OLPARS is a highly interactive software package which combines a very flexible system for data storage, display, and manipulation with powerful techniques for data structure analysis and classification. In the context of this research problem, OLPARS will make possible the evaluation of the separability of wheat from other small grains in various one or two dimensional subspaces. These include:

- a. Coordinate vector projections
- b. Eigenvector projections
- c. Fisher's discriminant vector projections
- d. Generalized discriminant vector projections
- e. Any arbitrary vector projections, such as projections onto the brightness-greenness space

In addition, OLPARS includes a routine for multidimensional scaling, which iteratively fits the data into a two or three dimensional subspace so that the difference between interpoint distances in the lower and higher dimensional spaces is as small as possible. Also included is the capability to perform any arbitrary linear transformation on the data before forming these projections.

The structure analysis capabilities of the OLPARS will allow a quick and easy assessment of the separability of wheat from other small grains in a number of different two dimensional subspaces. This should provide a good evaluation of the separability of wheat from other small grains in

the original space. More importantly, it will greatly facilitate the development of two dimensional plots or projections to be used as analyst labeling aids.

2.4.2 DATA SET

The data set for this study will consist of ground-truth-labeled grid intersection points in each of several segments, including approximately 20 segments from the 1976 crop year and approximately 25 segments from the 1977 crop year. For each segment the grid intersection pixels will be sorted by ground-truth class into wheat, barley, rye, oats, flax, and other. Each of these classes will be further divided into those pixels which are pure and those which are on a boundary. For example, there will be a pure wheat class and a boundary wheat class. Some of these classes may be combined later for analysis.

The radiance values for all of the acquisitions available for each segment will be recorded; however, no segment will be chosen unless it has at least three acquisitions.

These data will be obtained from the CAMS data base on the Programmed Data Processor, model 11/45 (PDP 11/45). The data will be sent to the Rome Air Development Center, where they will be stored for access by OLPARS.

2.4.3 ACQUISITION SELECTION FACTORS

Because wheat and other small grains are so similar spectrally, the key to reliable discrimination is believed to lie in their temporal or developmental differences. Therefore, the selection of appropriate Landsat acquisitions is very important. This study will examine the separability of wheat from other small grains as it relates to acquisition selection.

2.4.3.1 Separability as a Function of Crop Calendar Difference

Because wheat is usually planted at a different time than other small grains and because different small grains have a somewhat different developmental

pattern, the separability of wheat from other small grains will be a function of time. The only keys generally available for assessing these developmental differences are the crop calendars for wheat and for other small grains. This phase of the study will attempt to relate the spectral separability of wheat from other small grains to the differences in these crop calendars. Separability will be measured as the probability of correct classification (PCC) of ground-truth-labeled wheat dots using a standard OLPARS classification algorithm. The study will also make recommendations on the use of crop calendar information in selecting acquisitions likely to have the best separability of wheat from other small grains.

The anticipated steps for accomplishing this phase of the study follow:

- a. Select the segments and acquisitions.
- b. Classify the grid intersection points for wheat versus small grains for each segment and acquisition, using the OLPARS maximum likelihood classification.
- c. Plot the PCC values for each acquisition of a segment versus the difference in wheat and small grain crop calendars at the time of each acquisition.

2.4.3.2 Multitemporal Separability

It is not clear how the separability of wheat from other small grains is affected by using multiple acquisitions. This part of the study will examine the separability of wheat from other small grains as a function of the number of acquisitions used. The acquisitions will be chosen using crop calendar information. An attempt will be made to quantify the importance of acquisitions obtained at various times throughout the growing season.

The anticipated steps for accomplishing this phase of the study follow.

- a. Use the same data as in section 2.4.3.
- b. Classify the grid intersection points for wheat versus small grains, using two, three, and four acquisitions. (Use the OLPARS maximum likelihood classification.)
- c. Plot the PCC values versus the number of acquisitions used for several segments.

2.4.4 ANALYST AIDS

In order for the analyst to be able to reliably discriminate wheat from other small grains, it is necessary that he have more information than simply the standard film products, trajectory plots, scatter plots, and other currently available ancillary information. This research will examine alternative analyst aids in the form of two dimensional subspace projections and will make recommendations concerning procedures for using these aids for the labeling of wheat. Two different approaches for the development of these aids will be used, one for fixed projections and one for segment-dependent projections.

2.4.4.1 Fixed Projections

It may be possible to develop a fixed projection which can be used over a range of segments; for example, all of the segments in a stratum. Such a fixed projection would be particularly simple to use in operations and would be readily applicable to automated procedures such as Label Identification from Statistical Tabulation (LIST).

The feasibility of a fixed projection will be explored by combining data from several segments and searching for a projection which provides sufficient separability of wheat from other small grains. If such a projection is found, it will be tried on segments in different areas and different crop years. The degree to which the projection for separating wheat from other small grains can be extended from segment to segment and from year to year will be evaluated.

2.4.4.2 Segment-Dependent Projections

As an alternative to the fixed projection approach, a projection could be computed for each segment individually. This approach will be explored by searching for a type of projection that provides acceptable separability of wheat from other small grains when it is computed for each segment individually.

The best such segment-dependent projection will be evaluated by determining which projection operation gives the best separability for a number of different test segments coming from different regions and different crop years. An important consideration will be whether the axes that result from segment-dependent projections are sufficiently stable to allow consistent rules for discrimination and interpretation. Ideally, the axes produced should have some physical interpretation. A minimum requirement is that fairly consistent rules for discriminating wheat from other small grains need to be developed.

2.4.4.3 Development of Projections

The steps to be used in accomplishing the fixed and segment-dependent projections are the following:

- a. Select the segments. For the fixed projection problem, combine the data for several segments.
- b. Examine various two dimensional projections (i.e., Fisher's vector, eigenvector, generalized discriminate vector, and coordinate vector).
- c. Select the candidate projections.
- d. Determine the PCC values when dots are labeled using the candidate projections. Use segments in different strata and different years.
- e. Compare the PCC values for the Fisher's and generalized discriminant vector projections (which should be optional in a discrimination sense but which require labeled samples) to the eigenvector and coordinate vector projections (which do not require labeled samples).

2.4.5 SUMMARY

The goal of the research outlined in this plan will be to analyze acquisition selection and to develop analyst labeling aids. Both of these tasks will make use of the structure analysis and display capabilities of the OLPARS at the Rome Air Development Center. An overall consideration will be to develop techniques which are directly applicable from an operations standpoint. For this reason, the axes of the recommended projections will be as amenable to physical interpretation as possible. Also, procedures will be recommended for implementing acquisition selection techniques and analyst labeling aids for the discrimination of wheat from other small grains.

APPENDIX A
WHEAT ESTIMATION GUIDELINES AND PROCEDURE

APPENDIX A

WHEAT ESTIMATION GUIDELINES AND PROCEDURE

The ability to separate wheat from other small grains will depend on crop development patterns. The spectral reflectance patterns of spring wheat and other small grains are similar; however, general differences can be noted. These differences are:

- Barley is generally planted after wheat.
- Barley tends to green-up sooner than spring wheat and obtain higher levels.
- Barley turns and matures earlier than wheat.
- Barley tends to be brighter than wheat after heading.
- Rye is greener than wheat.
- Oats are not as green as wheat and may mature earlier than wheat.

The green-number growth pattern for small grains is shown in figure A-1 for general guidance. The assumption is that a field is wheat unless it can be shown that it is a nonwheat small grains. The production of wheat and other small grains in North Dakota is illustrated in figure A-2. Figure A-3 shows the process to be followed in deciding the wheat-small grains separation. The guidelines are designed to be flexible.

*Personal communication with D. R. Thompson of the Applications Systems Verification Branch of the National Aeronautics and Space Administration (NASA), June 1977.

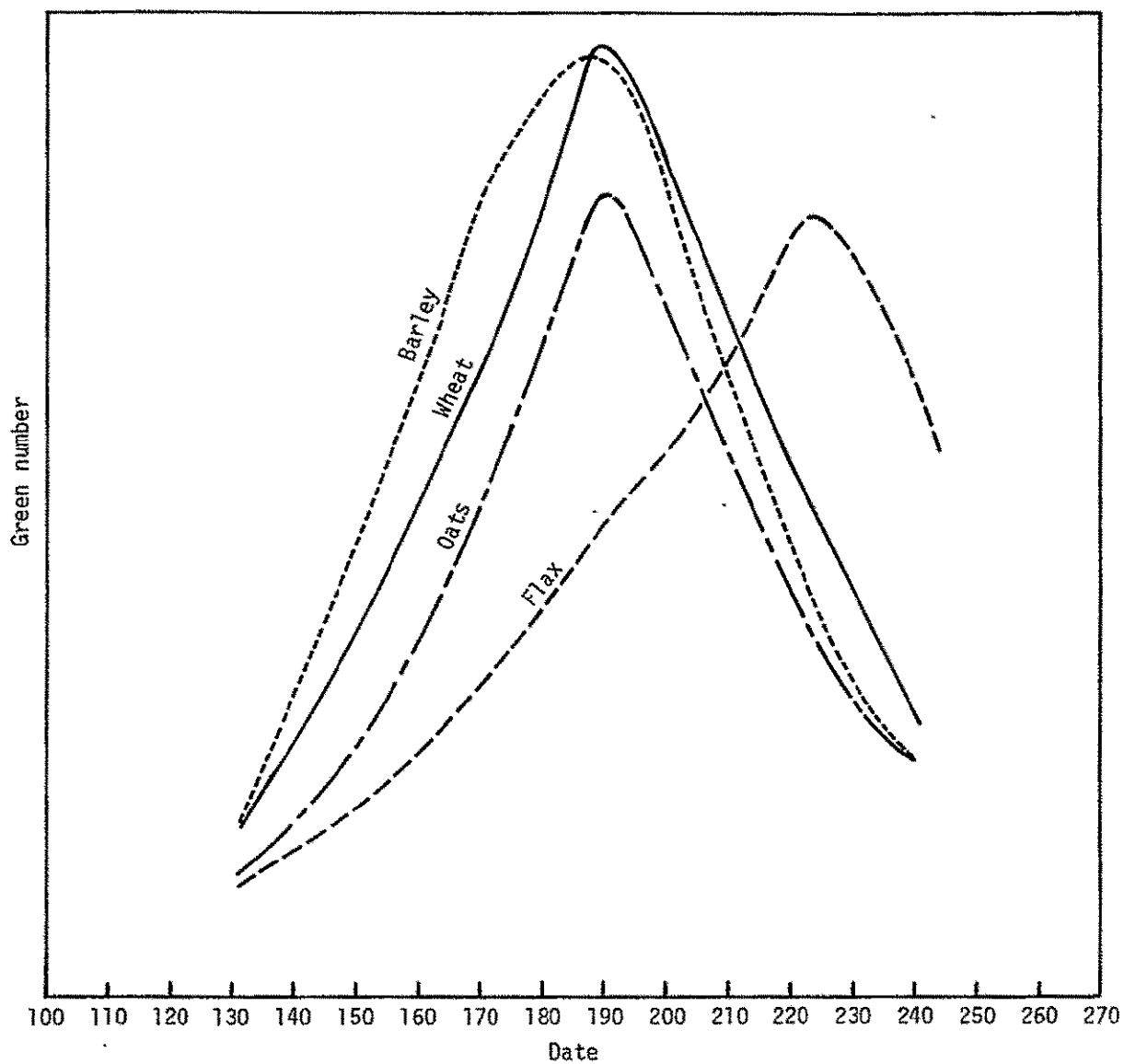


Figure A-1.— Green number growth pattern for small grains.

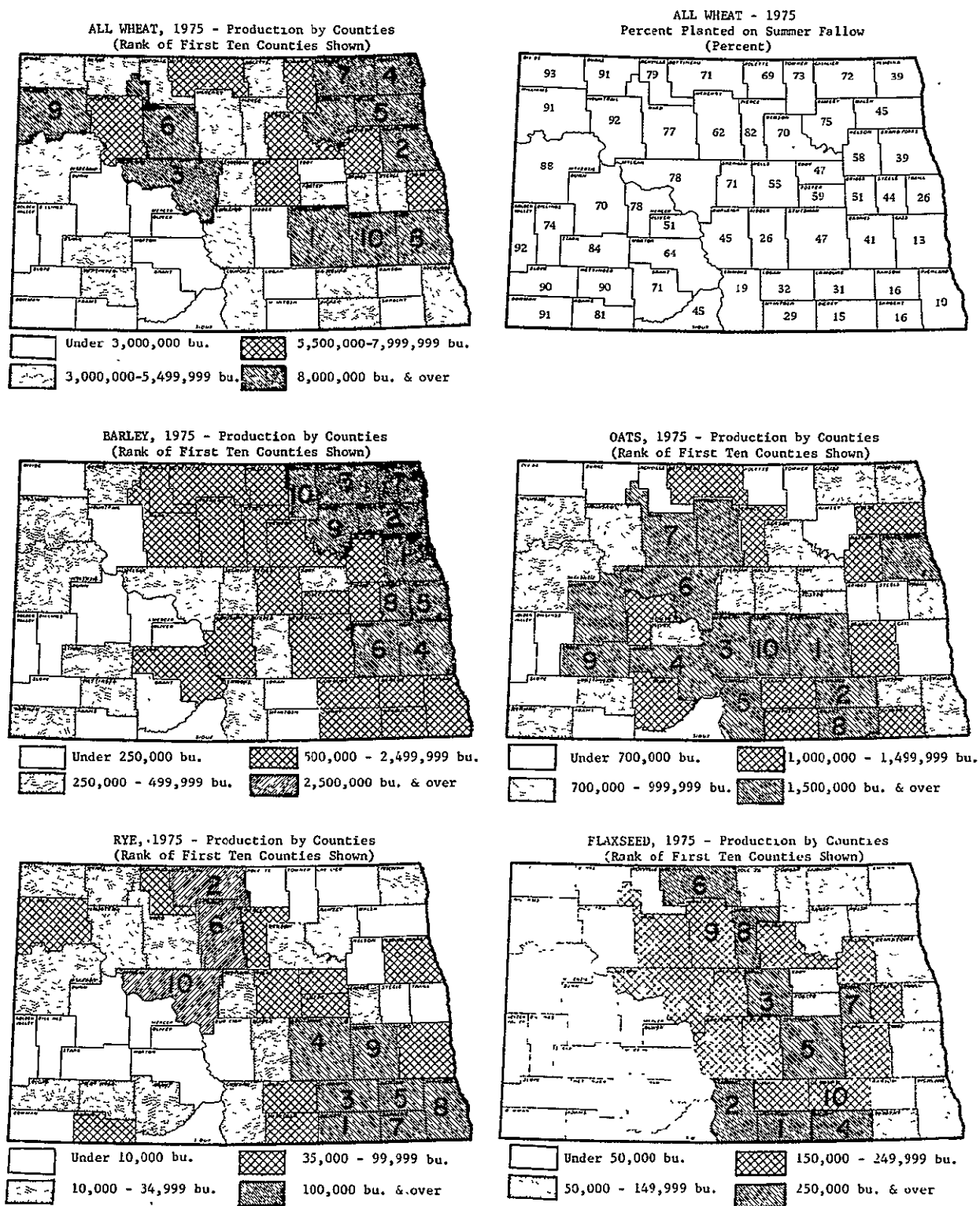


Figure A-2.— Production of wheat and other small grains in North Dakota.

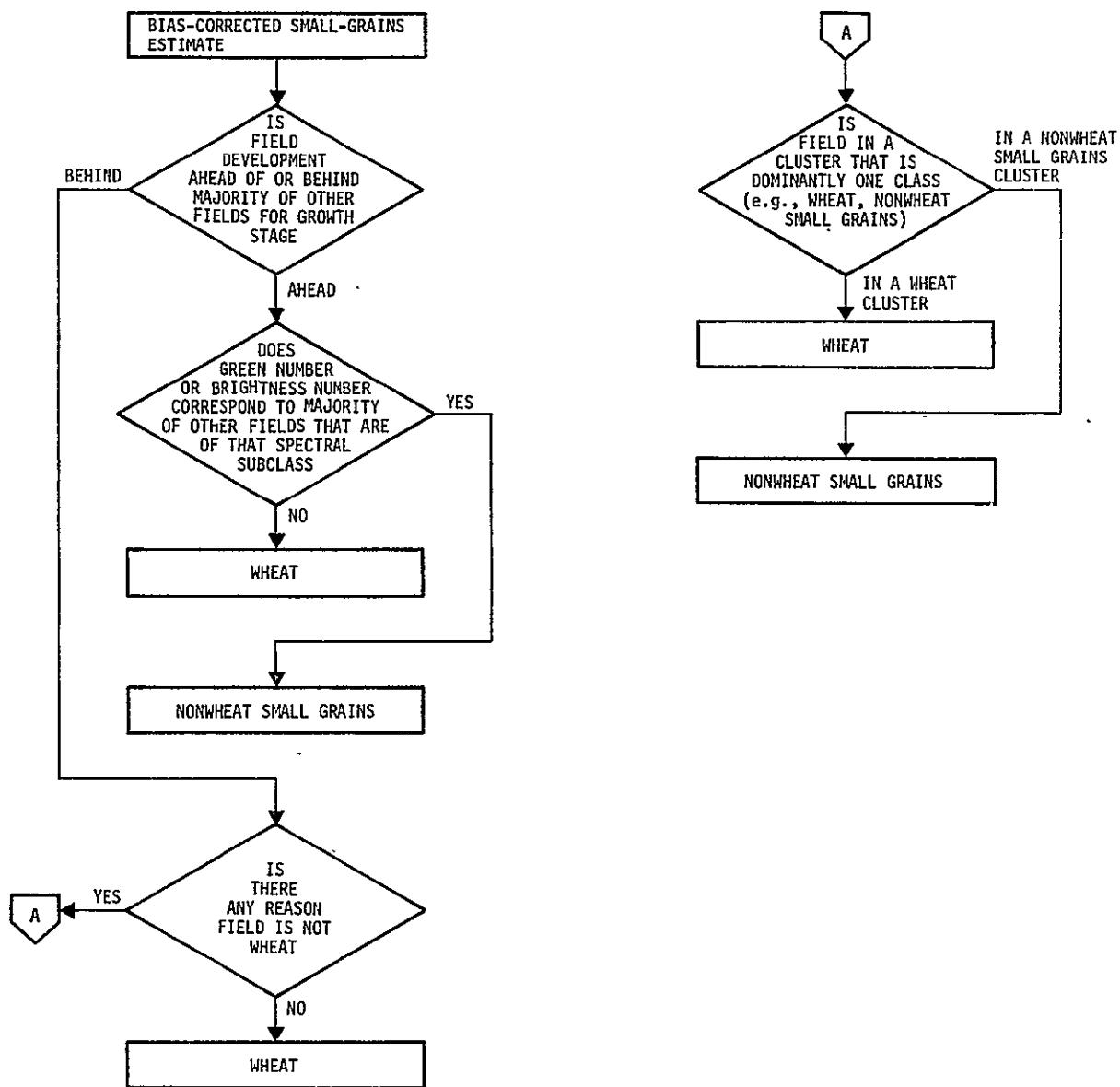


Figure A-3.— Decision logic for separating wheat from other small grains.

A.2 PROCEDURE FOR SEPARATING WHEAT FROM OTHER SMALL GRAINS*

1. The bias corrected small grains estimate has been evaluated as satisfactory.
2. Look at the 1975 county grain production maps to gain an understanding of the relative importance/ranking of each small grain in the county that the segment is located in. Use of the 9×9 's at this time to check the relationship between the segment and county might prove helpful (see section 3.3 of the Phase III CAMS Detailed Analysis Procedures[†] for amplification of use of Landsat full frames).
3. Look at the crop calendar and the Small Grains-Wheat Separation Guidelines to formulate some expected general spectral characteristics (greenness and brightness) for each small grain.
4. Look at the spectral plot of the base acquisition showing the classifier identified small grain and non-small grain pixels. Using the knowledge of the historical importance of each small grain in the county and the expected relative greenness and brightness position of each small grain, draw lines on the spectral plot to separate small grain classes. Label these small grain classes on the spectral plot (i.e., wheat, barley, oats, etc.) within the boundary lines drawn.
5. Locate each of the small grain pixels (using greenness and brightness values from the spectral plot) in table 1, the ordered listing by dot number.
6. For each pixel classified as an S (small grain) in the listing, indicate which grain class (wheat, barley, oats, etc.) previously indicated on the spectral plot that specific pixel belongs to. Put a symbol (W,B,O,R) to the right of the brightness value of that pixel in the table 1 base acquisition listing.

*Personal communication with D. R. Thompson of NASA's Applications Systems Verification Branch and J. D. O'Connell of Lockheed Electronics Company, Inc., June 1977.

[†]LACIE-00720, JSC-11693, August 1977.

7. Determine the total number of pixels classified as S in the classified column of table 1.
8. Tally the number of S pixels in each grain class (W,B,O,R).
9. Determine the proportion of classified small grain pixels for the wheat (W) class.

$$\frac{\text{Number of S pixels in the wheat class}}{\text{Total number pixels classified S}}$$

10. Determine the percentage of spring wheat for the segment.

$$(P_W)(\%S_{BCE}) = \% \text{ of spring wheat}$$

where

P_W = proportion of SW

S_{BCE} = bias corrected estimate for grains

11. Subtract the percentage of SW from the bias corrected estimate to obtain the percentage of other spring small grains in the segment.
12. Record the proportions of SW and other SG on the CAMS Evaluation Form (CEF) and Porta-punch cards.
13. Record all other information in the necessary places, put packet contents together in proper manner and turn packet over to the Spring Wheat/Small Grains Coordinator.

APPENDIX B
DATA TABLES

APPENDIX B

DATA TABLES

TABLE B-1.— ACCURACY OF ALL
MACHINE-CLASSIFIED DOTS

		Machine			Segment: _____
		SG	N	Total	Separation: _____
Ground truth	SG				
	N				
	Total	X	Y	≤209	

TABLE B-2.— ACCURACY OF ALL
DOTS MACHINE-CLASSIFIED
AS NONSMALL GRAINS

		Machine	
		IN	
Ground truth	SW		
	B		
	O		
	N		
	Total	Y	

TABLE B-3.— ACCURACY OF METHOD FOR MACHINE-CLASSIFIED DOTS
WITH SEPARATION LABEL

		Analyst/machine			
		SW	B	O	N_1^{SG} Total
Ground truth	SW				
	B				
	O				
	N				
	Total				

N_1 — Machine classified SG but
analyst labeled NSG

Statistics from Accuracy
Assessment (AA) printout:

		GT	M/AI
GT	{	$p(1, *)$	_____
		$p(2, *)$	_____
		$p(3, *)$	_____
		$p(4, *)$	_____
		$p(5, *)$	_____
		$p(6, *)$	_____
M/AI	{	$p(*, 1)$	_____
		$p(*, 2)$	_____
		$p(*, 3)$	_____
		$p(*, 4)$	_____
		$p(*, 5)$	_____
		$p(*, 6)$	_____

Statistics from printout:

% ground truth data pure pixels _____
% 209 pure pixels _____

Key:

1 — Wheat 4 — Oats
2 — Barley 5 — Alfalfa
3 — Flax-rye 6 — N-other

TABLE B-4.— ACCURACY OF METHOD FOR
ANALYST-LABELED DOTS

		Analyst				
		SW	B	O	N	Total
Ground truth	SW					
	B					
	O					
	N					
	Total					

TABLE B-5.— ACCURACY OF ANALYST-LABELED
DOTS WHICH MACHINE CLASSIFIED AS OTHER

		Analyst		
		SG	N	Total
Ground truth	SG			
	N			
	Total			

APPENDIX C
TABULATION TABLES

APPENDIX C
TABULATION TABLES

TABLE C-1.- ACCURACY OF MACHINE CLASSIFICATION

AI GT
TAPE GT

SEGMENT:

SEPARATION:

		Machine		
		SG	N	Total
Ground truth	SG	(1)		(2)
	N		(4)	(6)
	Total	(3)	(5)	≤209
		X	Y	

1. $Pr (M = SG/GT = SG) = \frac{(1)}{(2)}$

2. $Pr (GT = SG/M = SG) = \frac{(1)}{(3)}$

3. $Pr (\text{correct classification}) = \frac{(1) + (4)}{(3) + (5)}$

4. $Pr (M = N/GT = N) = \frac{(4)}{(6)}$

TABLE C-2.- RATIO OF WHEAT TO OTHER SMALL GRAINS

		Machine	
		N	
Ground truth	SW	(1)	
	B	(2)	
	O	(3)	
	N	(4)	
	Total	(5)	
		Y	

1. Actual ratio of SW to SG
for dots classified N = $\frac{(1)}{(1) + (2) + (3)}$

2. $Pr (GT = N/M = N) = \frac{(4)}{(5)}$

TABLE C-3.— ACCURACY OF METHOD FOR MACHINE-CLASSIFIED DOTS
WITH SEPARATION LABEL

		Machine				
		SW	B	O	N_1^{SG}	Total
Ground truth	SW	(1)	(18)		(15)	(2)
	B		(3)		(16)	(4)
	O				(17)	(6)
	N	(9)	(10)	(11)	(7)	(8)
	Total	(12)	(13)	(14)	(20)	(21)

N_1 — Machine classified SG but
analyst labeled NSG

SEGMENT: _____

SEPARATION: _____

GT TYPE: _____

1. Accuracies

a. Spring wheat:

$$\Pr (AI = SW/GT = SW \ \& \ M = SG) = \frac{(1)}{(2)}$$

$$\Pr (GT = SW/AI = SW \ \& \ M = SG) = \frac{(1)}{(12)}$$

b. Barley:

$$\Pr (AI = B/GT = B \ \& \ M = SG) = \frac{(3)}{(4)}$$

$$\Pr (GT = B/AI = B \ \& \ M = SG) = \frac{(3)}{(13)}$$

c. Oats:

$$\Pr (AI = O/GT = O \ \& \ M = SG) = \frac{(5)}{(6)}$$

$$\Pr (GT = O/AI = O \ \& \ M = SG) = \frac{(5)}{(14)}$$

TABLE C-3.— Continued

d. Nonwheat:

$$\Pr (AI = N/GT = N \ \& \ M = SG) = \frac{(7)}{(8)}$$

e. Small grains:

$$\Pr (AI = SG/GT = SG \ \& \ M = SG) = \frac{(12) + (13) + (14) - (9) - (10) - (11)}{(2) + (4) + (6)}$$

$$\Pr (GT = SG/AI = SG \ \& \ M = SG) = \frac{(2) + (4) + (6) - (15) - (16) - (17)}{(12) + (13) + (14)}$$

f. Ratios:

Analyst estimate of ratio of SW to SG
for dots classified SG =

$$\frac{(12)}{(12) + (13) + (14)}$$

Actual ratio of SW to SG for dots
classified SG =

$$\frac{(2)}{(2) + (4) + (6)}$$

g. Correct labeling overall:

$$\Pr (\text{correct labeling overall}) = \frac{(1) + (3) + (5) + (7)}{(21)}$$

TABLE C-3.— Concluded

2. Confusions

a. Barley:

$$\Pr (AI = B/GT = SW \ \& \ M = SG) = \frac{(18)}{(2)}$$

$$\Pr (GT = SW/AI = B \ \& \ M = SG) = \frac{(18)}{(13)}$$

b. Oats:

$$\Pr (AI = O/GT = SW \ \& \ M = SG) = \frac{(19)}{(2)}$$

$$\Pr (GT = SW/AI = O \ \& \ M = SG) = \frac{(19)}{(14)}$$

c. Nonsmall grains:

$$\Pr (AI = N/GT = SW \ \& \ M = SG) = \frac{(15)}{(2)}$$

$$\Pr (GT = SW/AI = N \ \& \ M = SG) = \frac{(15)}{(20)}$$

d. Spring wheat:

$$\Pr (AI = SW/GT \neq SW \ \& \ M = SG) = \frac{(22) + (23) + (9)}{(4) + (6) + (8)}$$

TABLE C-4.— ACCURACY OF METHOD FOR ANALYST-LABELED DOTS

AI GT
 TAPE GT

SEGMENT: SEPARATION:

		Analyst				Total
		SW	B	O	N	
Ground truth	SW	(1)	(14)	(15)	(16)	(2)
	B		(4)		(2)	(5)
	O			(7)	(21)	(8)
	N	(17)	(18)	(19)	(10)	(11)
	Total	(3)	(6)	(9)	(12)	(13)

1. Accuracies

a. Spring wheat:

$$\Pr (AI = SW/GT = SW) = \frac{(1)}{(2)}$$

$$\Pr (GT = SW/AI = SW) = \frac{(1)}{(3)}$$

b. Barley:

$$\Pr (AI = B/GT = B) = \frac{(4)}{(5)}$$

$$\Pr (GT = B/AI = B) = \frac{(4)}{(6)}$$

c. Oats:

$$\Pr (AI = O/GT = O) = \frac{(7)}{(8)}$$

$$\Pr (GT = O/AI = O) = \frac{(7)}{(9)}$$

d. Nonwheat:

$$\Pr (AI = N/GT = N) = \frac{(10)}{(11)}$$

$$\Pr (GT = N/AI = N) = \frac{(10)}{(12)}$$

TABLE C-4.— Concluded

e. Overall accuracy:

$$\text{Overall accuracy} = \frac{(1) + (4) + (7) + (10)}{(13)}$$

f. Probability of correct labeling:

$$\text{Pr (correct label/GT = SG)} = \frac{(1) + (4) + (7)}{(2) + (5) + (8)}$$

2. Confusions

a. Barley:

$$\text{Pr (AI = B/GT = SW)} = \frac{(14)}{(2)}$$

$$\text{Pr (GT = SW/AI = B)} = \frac{(14)}{(6)}$$

b. Oats:

$$\text{Pr (AI = O/GT = SW)} = \frac{(15)}{(2)}$$

$$\text{Pr (GT = SW/AI = O)} = \frac{(15)}{(9)}$$

c. Nonsmall grains:

$$\text{Pr (AI = N/GT = SW)} = \frac{(16)}{(2)}$$

$$\text{Pr (GT = SW/AI = N)} = \frac{(16)}{(12)}$$

d. Small grains:

$$\text{Pr (AI = SG/GT = SG)} = \frac{(3) + (6) + (9) - (17) - (18) - (19)}{(2) + (5) + (8)}$$

$$\text{Pr (GT = SG/AI = SG)} = \frac{(2) + (5) + (8) - (16) - (20) - (21)}{(3) + (6) + (9)}$$

TABLE C-5.— ACCURACY OF ANALYST-LABELED DOTS WHICH
MACHINE CLASSIFIED AS OTHER (N)

		Analyst			SEGMENT: _____
		SG	N	Total	
Ground truth	SG	(1)		(2)	SEPARATION: _____ GT TYPE: _____
	N		(4)	(5)	
	Total	(3)		(6)	

1. $\Pr (AI = SG/GT = SG \ \& \ M = N) = \frac{(1)}{(2)}$
2. $\Pr (GT = SG/AI = SG \ \& \ M = N) = \frac{(1)}{(3)}$
3. $\Pr (AI = N/GT = N \ \& \ M = N) = \frac{(4)}{(5)}$
4. $\Pr (\text{correct labeling}/M = N) = \frac{(1) + (4)}{(6)}$

TABLE C-6.— OVERALL ACCURACY OF THE PROCEDURE

1. Computation of ratios from the analyst-interpreted estimates:

$$\text{Direct wheat ratio} = \frac{AI \ SW \ \%}{BCE \ SG \ \%}$$

$$GT \ ratio = \frac{GT \ SW \ \%}{GT \ SG \ \%}$$
2. Comparison of proportions for spring wheat and for small grains:

$$AI \ SW \ \% - GT \ SW \ \% = \Delta SW$$

$$AI \ SG \ \% - GT \ SG \ \% = \Delta SG$$

APPENDIX D

GRAPHIC REPRESENTATION OF GROUND-TRUTH DATA FOR
SPRING WHEAT, BARLEY, OATS, AND FLAX

GRAPHIC REPRESENTATION OF GROUND-TRUTH DATA FOR SPRING WHEAT, BARLEY, OATS, AND FLAX

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[illegible]

Time: Time is expressed in 9-day increments, where

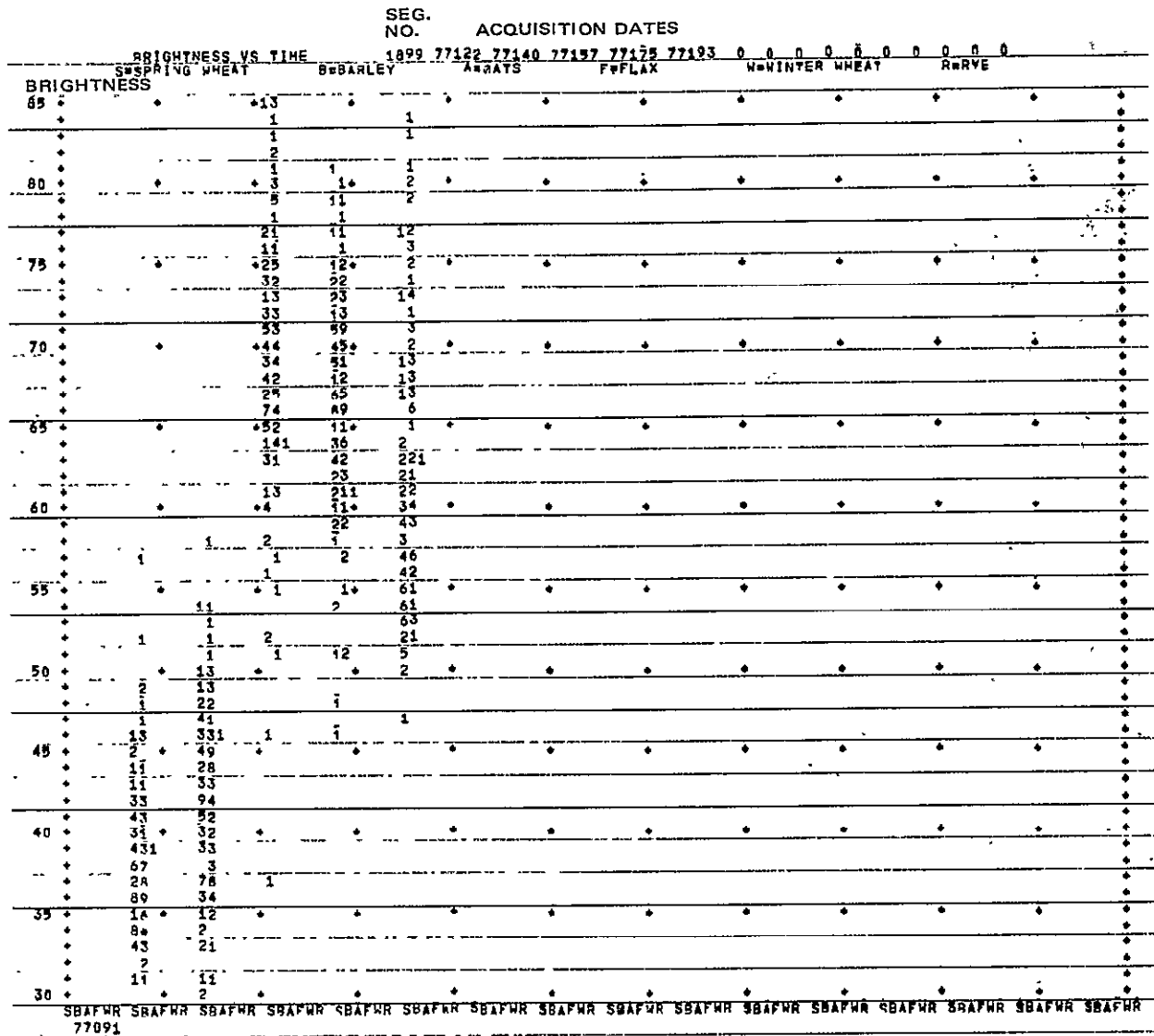
WW - September 1 through September 1 (omitting January and February)

Columns: There are six columns per increment in the following order (left to right): spring wheat (S), barley (B), oats (A), flax (F), winter wheat (W), and rye (R).

Data representation: The data points are represented with digits reflecting the number of hits for that point. An asterisk (*) is used for all digits over 9.

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PLOT D-2.— BRIGHTNESS VERSUS TIME



Brightness: Each space on the vertical axis represents a brightness value.

Time: Time is expressed in 9-day increments, where

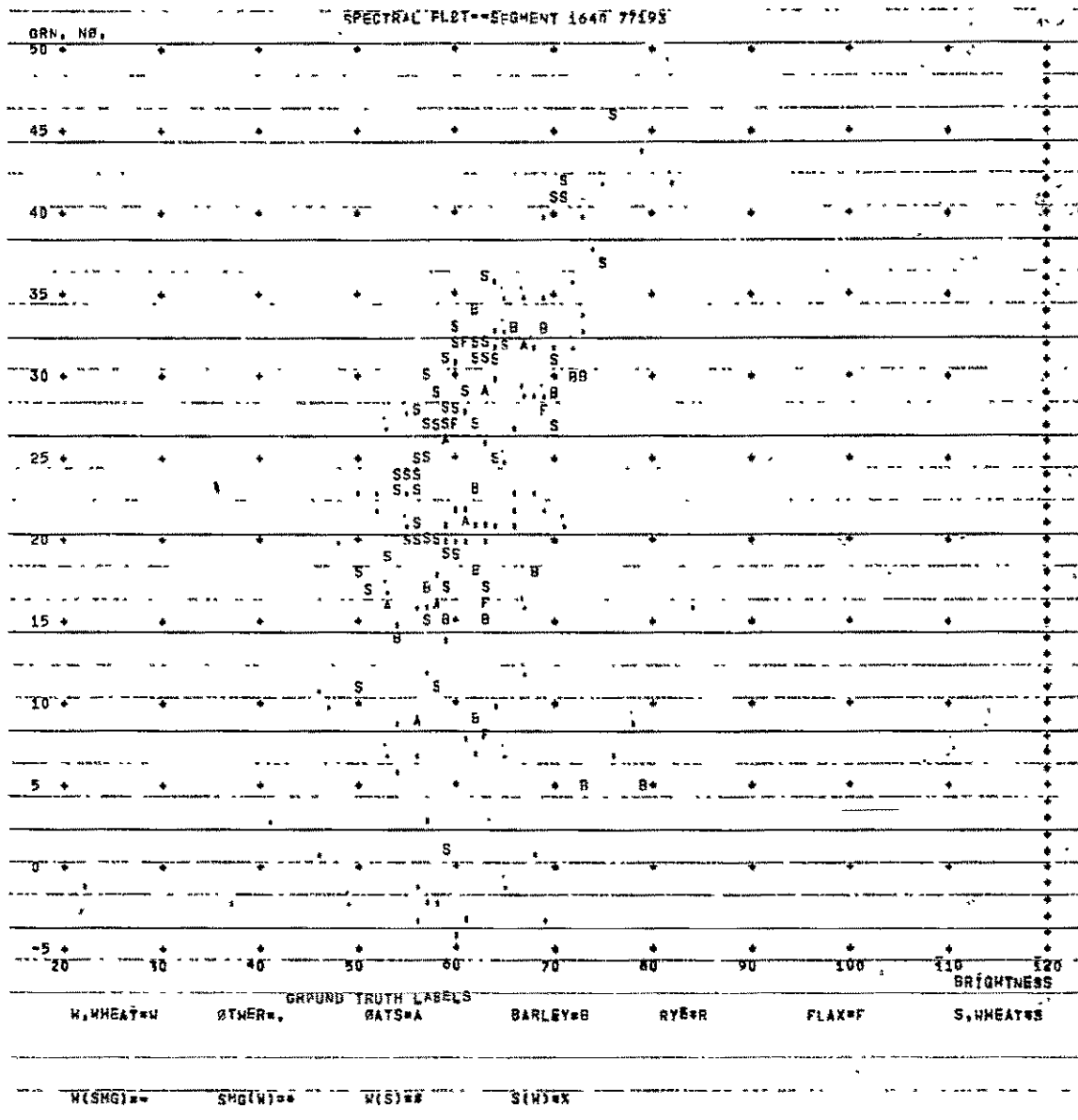
SW — April 1 through September 30

WW — September 1 through September 1 (omitting January and February)

Data representation: The data points are represented with digits reflecting the number of hits for that point. An asterisk (*) is used for all digits.

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PLOT D-3.- GREEN NUMBER VERSUS BRIGHTNESS



Note: This scatter plot is provided for each acquisition.

Green number: Each space on the vertical axis represents one green number.

Brightness: Each space on the horizontal axis represents one brightness value.

Data representation: A data point is represented by the letter of the last hit.

Listings: Two listings of data are provided for each plot, one ordered by green number and one ordered by brightness value.

PLOT D-3.- Continued

(a) Listing ordered by green number

SEG. ACQ.
NO. DATE
1640 77193

LINE	PIXEL	GR. NO.	GR.	BORD. LAB	ST. LAB.
9	11	4.3	59.7		0
8	17	3.4	48.6		0
8	7	2.9	60.9		0
3	7	2.5	55.6		0
1	12	2.4	36.7		0
1	8	2.3	46.5		0
7	10	2.1	49.5		0
6	13	1.5	58.4		0
5	11	1.2	46.2		0
5	12	0.8	44.5		0
2	5	0.6	21.8		0
8	18	0.6	48.2		0
5	2	1.0	45.8		0
10	19	1.1	59.4		S
2	1	1.1	59.0		F
2	15	2.7	58.7		0
2	2	3.3	57.3	S	0
6	7	3.3	41.0		0
3	12	4.7	73.2		0
3	11	5.0	79.2		0
2	6	5.1	66.8	0	A
6	17	5.8	54.5		0
2	9	6.3	20.9	0	0
2	11	6.6	52.9		0
2	16	7.0	43.2		0
6	18	7.1	65.0		0
3	15	7.1	76.2		0
5	13	7.3	62.2		0
6	16	7.5	56.5		0
7	12	8.0	60.9		0
7	3	8.0	62.7		F
3	9	8.6	54.1		0
9	3	8.7	42.1		0
9	7	8.8	61.9		0
1	15	8.9	56.2		A
1	13	9.3	77.7		0
11	16	9.6	48.8		0
5	3	10.1	58.1		0
7	14	10.3	43.7		0
8	6	10.6	45.9		0
3	10	10.7	50.2		S
8	15	11.4	58.2		S
8	8	11.8	57.1		0
9	18	12.3	67.3		0
6	11	13.9	54.0		0
2	7	13.9	59.1		0
3	2	14.4	53.9	0	S
11	14	14.6	56.9		0
4	8	14.6	43.1		0
6	19	15.0	57.3	0	S
6	2	15.2	54.4		0
7	13	15.3	58.6		0
1	16	15.6	63.7		0
10	14	15.7	48.0		A
5	15	15.8	56.4		0
8	9	15.9	66.9		0

1640 77193 0

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PLOT D-3.- Concluded

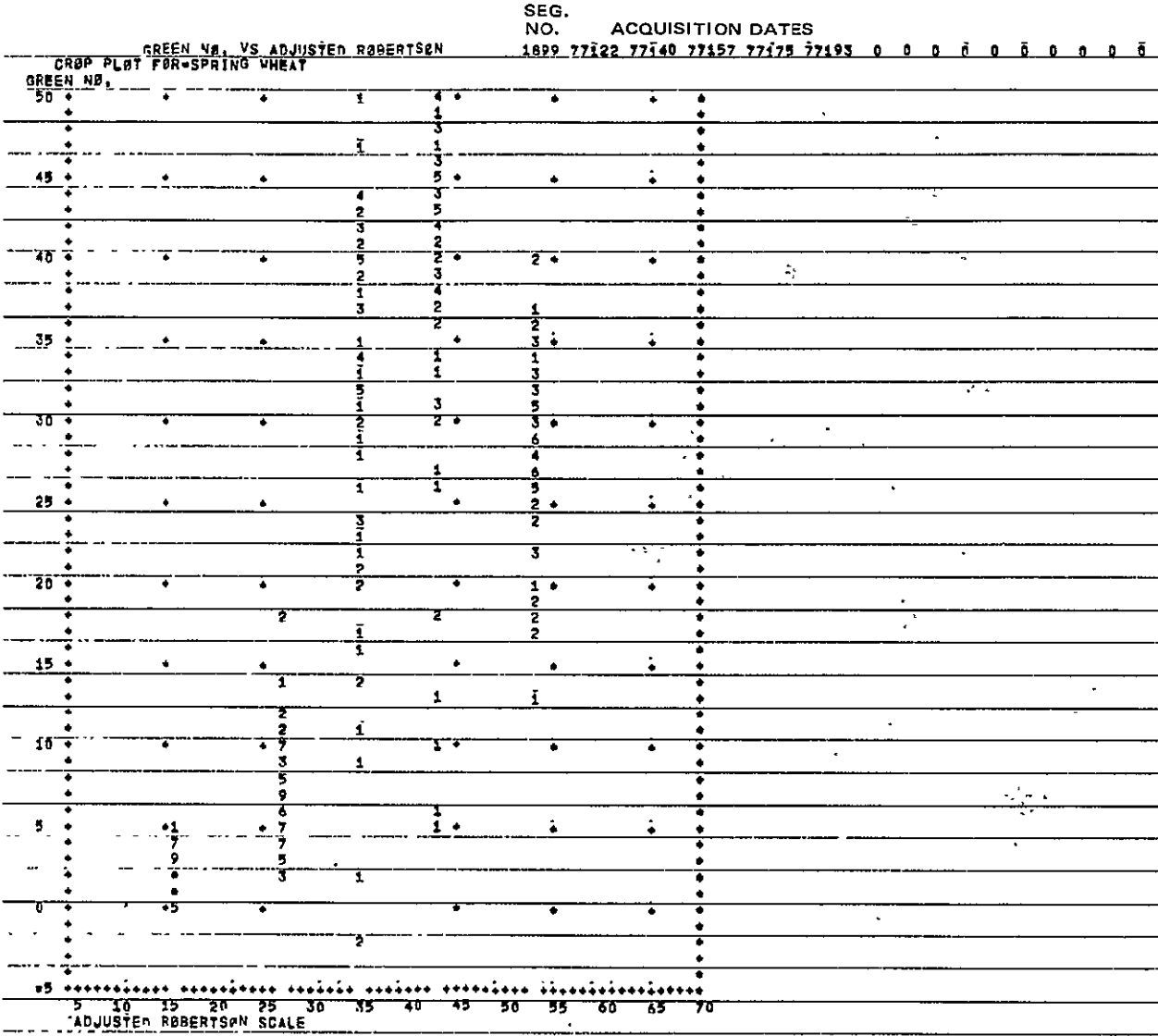
(b) Listing ordered by brightness value

SEG. ACQ.
NO. DATE
1640 77193

LINE	PIXEL	GR.NO.	DR.	90RD.LAB	ST.LAB.
1	16	15.6	83.7		0
10	10	41.9	81.7		0
3	11	5.0	79.2		0
5	8	44.2	78.8		0
1	13	9.3	77.7		0
3	15	7.1	76.2		0
1	5	46.0	75.8		S
9	13	41.6	74.6		0
6	1	37.0	74.6		S
9	12	37.7	74.5		0
9	19	34.8	73.2		0
3	12	4.7	73.2		0
11	9	33.4	72.9		0
9	8	39.6	72.6	S	0
3	4	30.1	72.6		0
3	6	29.7	72.3		0
10	2	35.9	72.1		0
11	18	31.7	72.1		0
10	7	41.0	71.2		S
7	9	42.5	71.1		S
11	2	21.0	70.8		0
5	19	28.9	70.4		0
2	3	31.6	70.4		0
4	9	41.3	70.3		S
7	8	31.3	70.2		S
10	18	26.6	69.6		S
4	16	27.6	69.3		F
3	5	32.9	69.2		0
9	17	22.3	69.0	B	0
9	1	29.4	68.9		0
8	17	33.4	68.8		0
5	18	35.3	68.8		0
7	1	39.9	68.8		0
1	1	23.5	68.5		0
4	10	31.6	68.4		0
8	18	0.6	68.2		0
4	6	17.9	68.1		0
8	5	28.7	67.6		0
5	17	32.2	67.4		A
1	10	34.8	67.4		0
9	18	12.3	67.3		0
8	9	15.9	66.9		0
2	6	5.1	66.8	F	A
11	3	29.0	66.6		0
11	17	20.6	66.2	B	0
1	19	33.0	66.1		0
11	13	27.1	66.0		0
3	13	22.9	65.7		0
10	13	21.9	65.5		0
8	2	32.9	65.5		S
6	8	33.1	65.3	S	0
6	18	7.1	65.0		0
10	9	32.3	64.8	0	S
11	8	24.8	64.6	0	S
10	3	35.0	64.6		0
4	11	25.5	64.6		0

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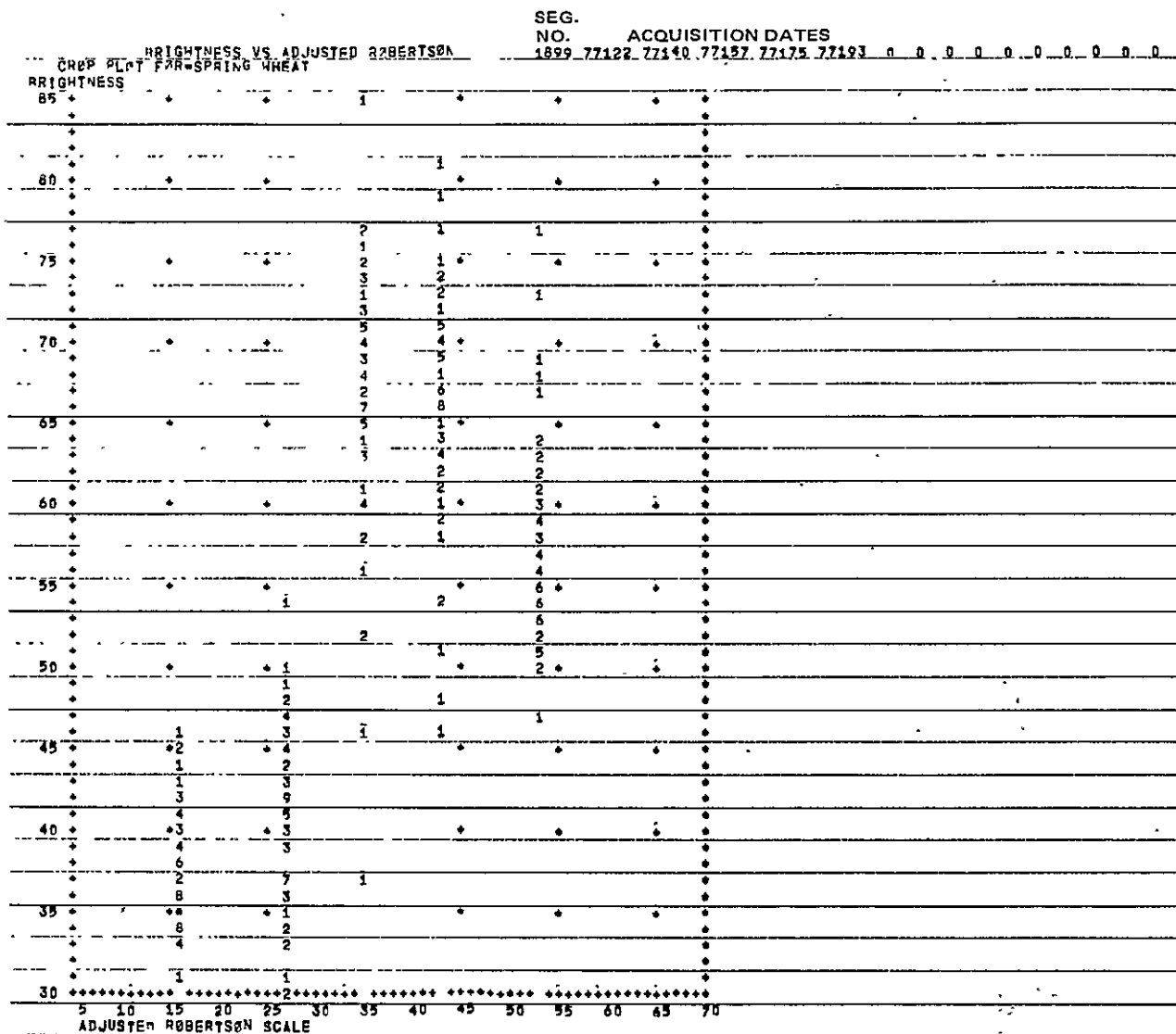
Note: Separate graphs are plotted for spring wheat, barley, oats, and flax ground-truth data.

Green number: Each space on the vertical axis represents one green number.

Robertson scale: Each space on the horizontal axis represents one-tenth.

Data representation: Data points are represented with digits reflecting the number of hits at that point. An asterisk (*) is used for all digits over 9.

PLOT D-5.— BRIGHTNESS VERSUS ADJUSTED ROBERTSON SCALE .



Note: Separate graphs are plotted for spring wheat, barley, oats, and flax ground-truth data.

Brightness: Each space on the vertical axis represents one brightness value.

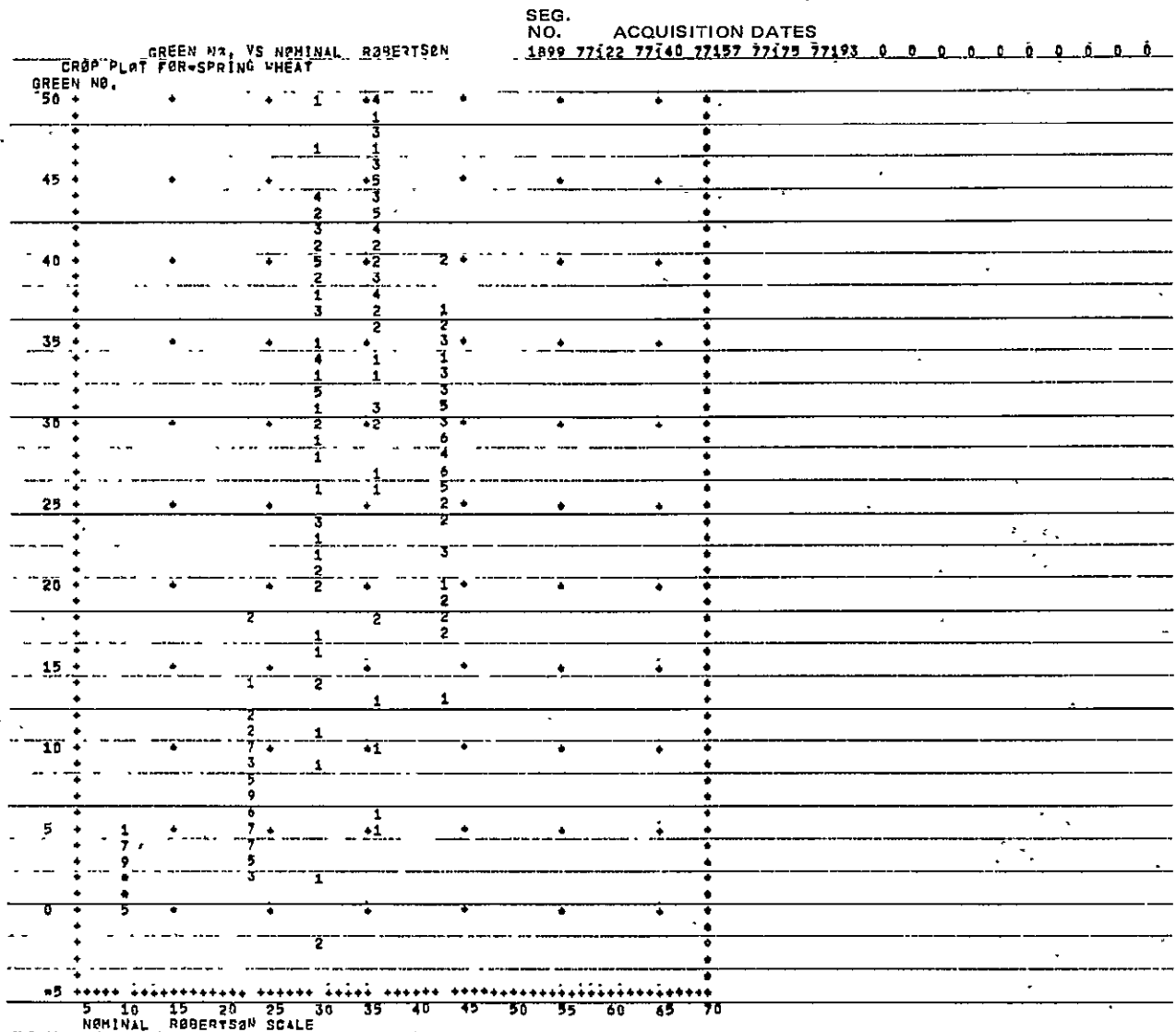
Robertson scale: Each space on the horizontal axis represents one-tenth.

Data representation: Data points are represented with digits reflecting the number of hits at that point. An asterisk (*) is used for all digits over 9.

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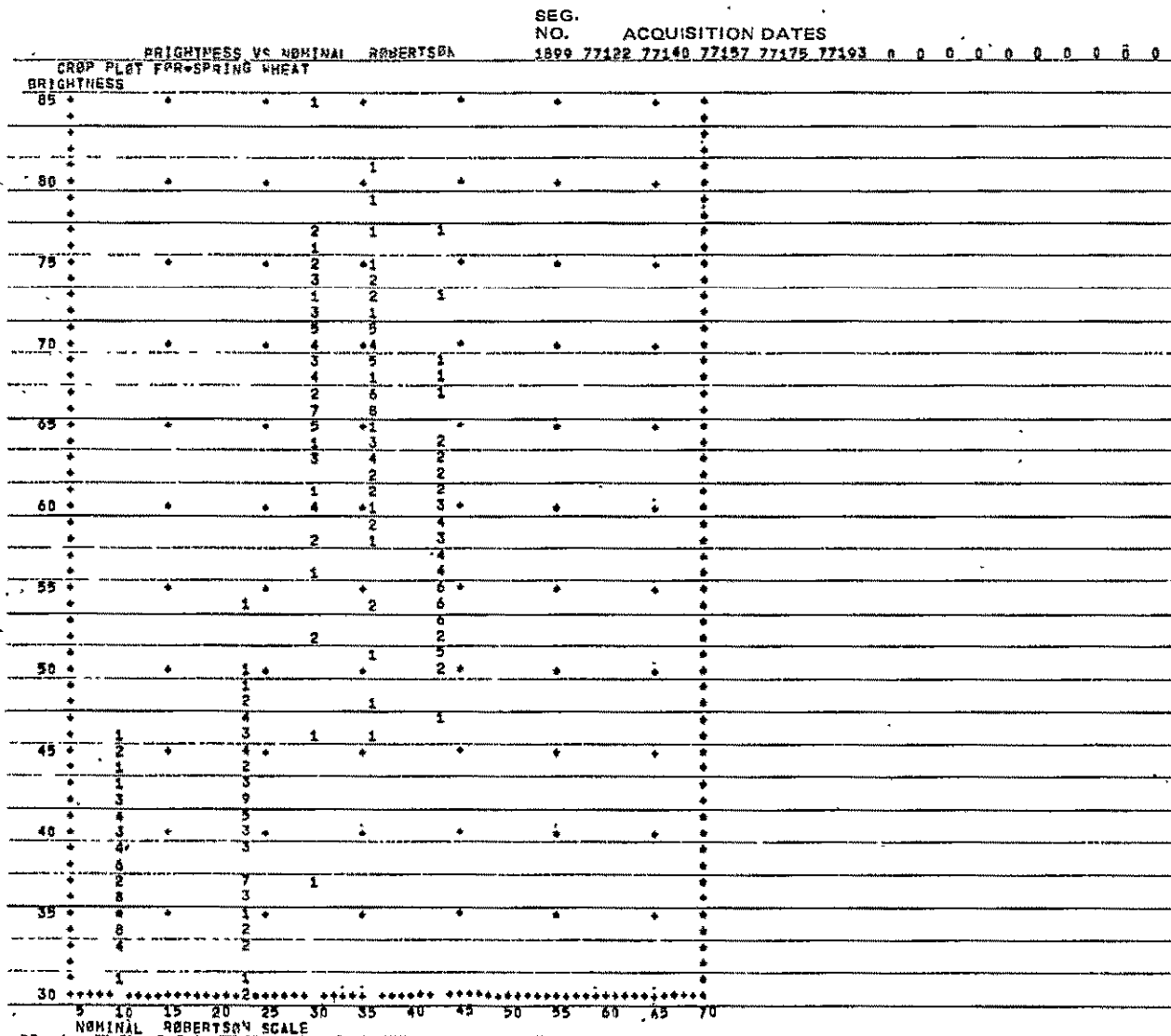
PLOT D-6.— NOMINAL CROP CALENDAR PLOTS

(a) Green number versus nominal Robertson scale — crop plot for spring wheat



PLOT D-6.- Continued

(b) Brightness versus nominal Robertson scale - crop plot for spring wheat



PLOT D-6.— Continued

(c) Green number versus nominal Robertson scale — crop plot for barley

GREEN NO. VS NOMINAL ROBERTSON				SEG. NO.	ACQUISITION DATES											
CROP PLOT FOR BARLEY				1899	77122	77140	77157	77175	77193	0	0	0	0	0	0	0
GREEN NO.																
50	*	6	5	*	*	*	*	*	*	*	*	*	*	*	*	*
		2	3													
		1	1													
		1	2													
		4	6													
45	*	2	6	1*	*	*	*	*	*	*	*	*	*	*	*	*
		2	2													
		4	3													
		4	5	1												
40	*	2	2	2*	*	*	*	*	*	*	*	*	*	*	*	*
		2	3													
		1	2	1												
		1	2													
		1	5	1												
		2	3	2												
35	*	5	3	*	*	*	*	*	*	*	*	*	*	*	*	*
		2	1	1												
		1	1	6												
		4	1													
		3		3												
30	*	2	1	1*	*	*	*	*	*	*	*	*	*	*	*	*
		1	1	3												
		1	1	2												
		1	1	2												
		1	1	1												
25	*	2	1	4*	*	*	*	*	*	*	*	*	*	*	*	*
		2	1	1												
		2	1	4												
		1	1	1												
20	*	1	1	4	*	*	*	*	*	*	*	*	*	*	*	*
		2	1	1												
		1	1	5												
		2	1	3												
		2	1	4												
15	*	2	*	5*	*	*	*	*	*	*	*	*	*	*	*	*
		2		1												
		1														
		4		1												
		3		2												
10	*	6	1	2*	*	*	*	*	*	*	*	*	*	*	*	*
		3														
		6														
5	2	6	1	1	*	*	*	*	*	*	*	*	*	*	*	*
		7														
		3														
		1	1													
		4														
		2														
0	7	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		1														
5	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
	5	10	15	20	25	30	35	40	45	50	55	60	65	70		
	NOMINAL ROBERTSON SCALE															

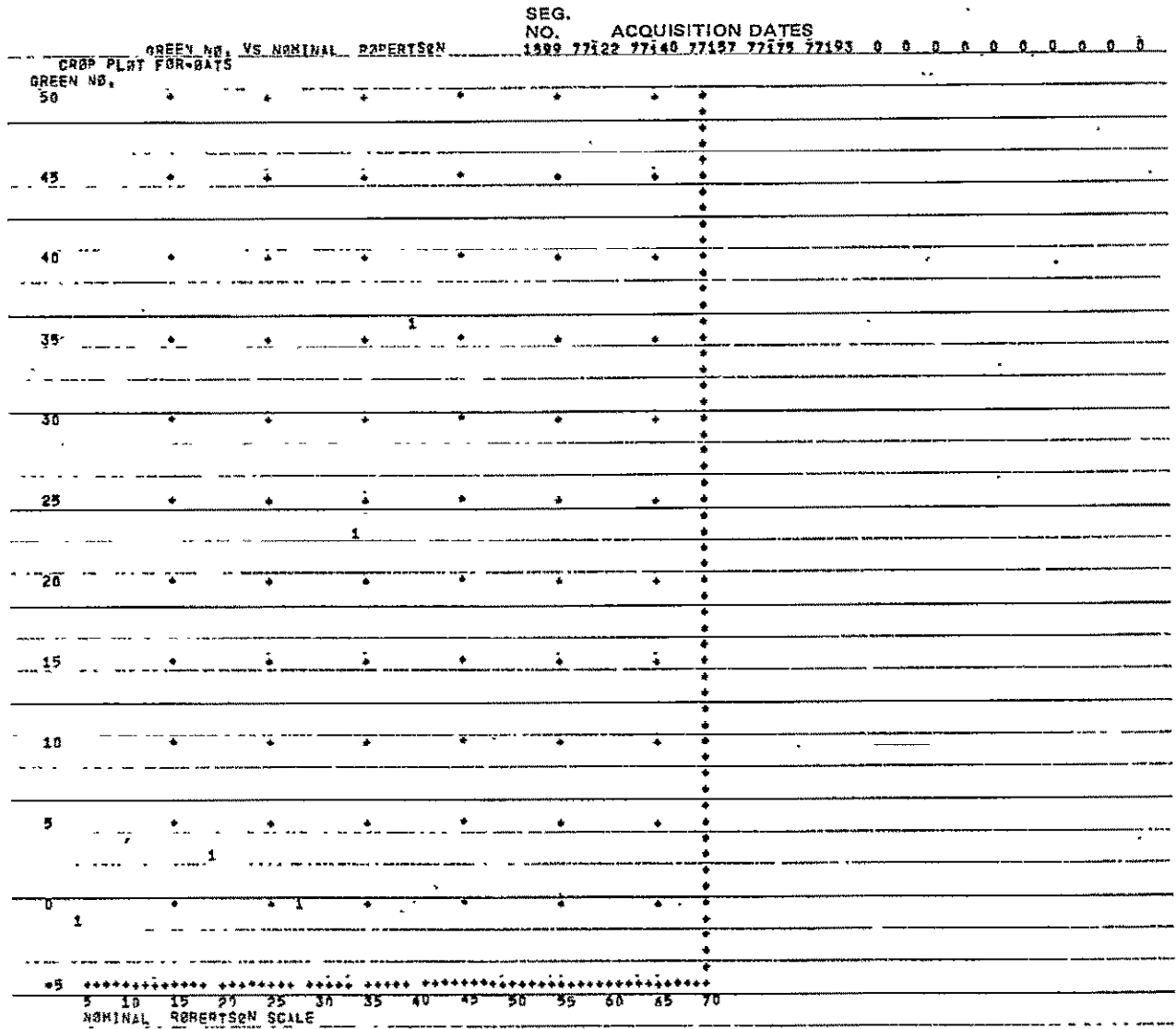
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(d) Brightness versus nominal Robertson scale – crop plot for barley



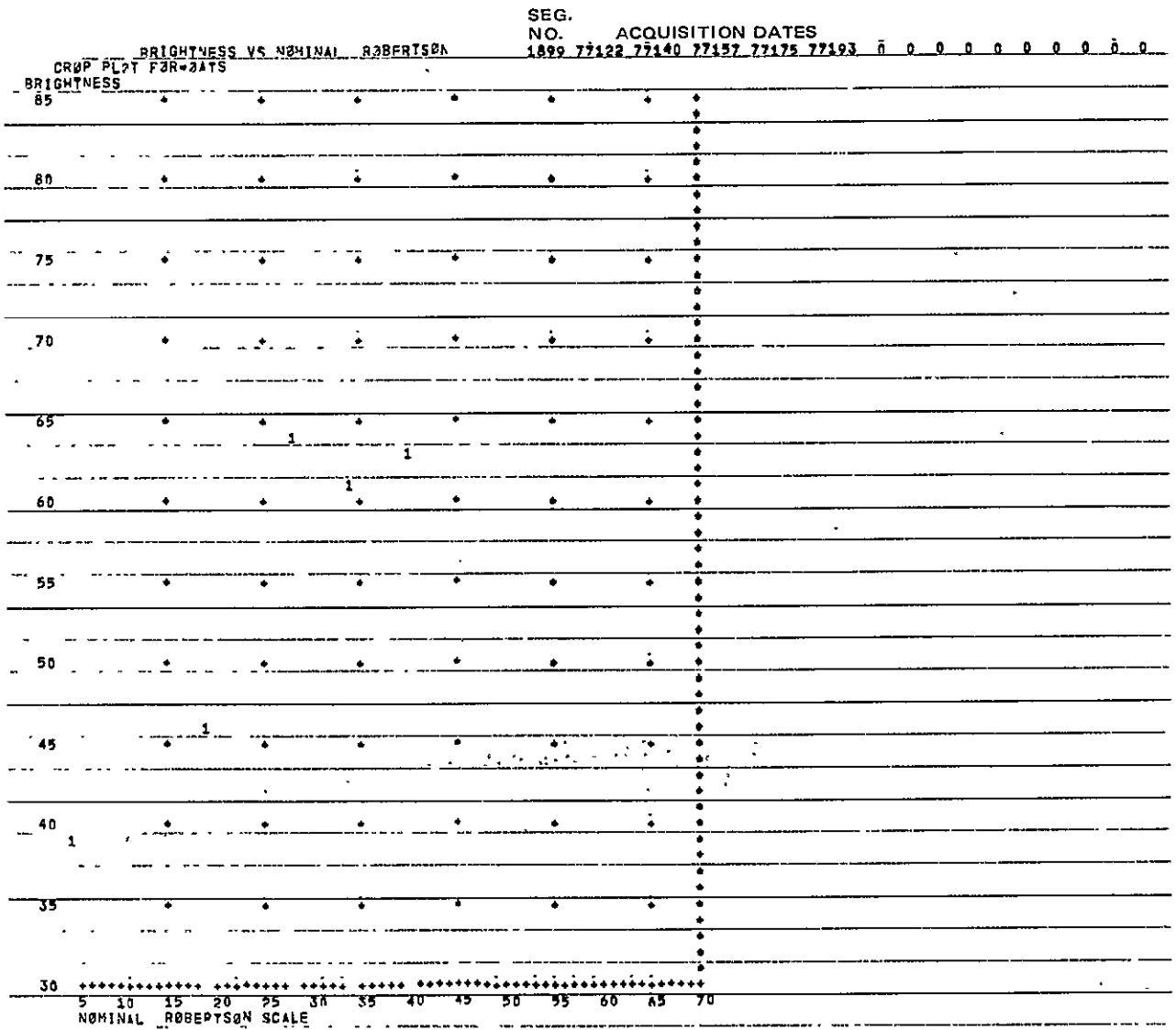
PLOT D-6.— Continued

(e) Green number versus nominal Robertson scale — crop plot for oats



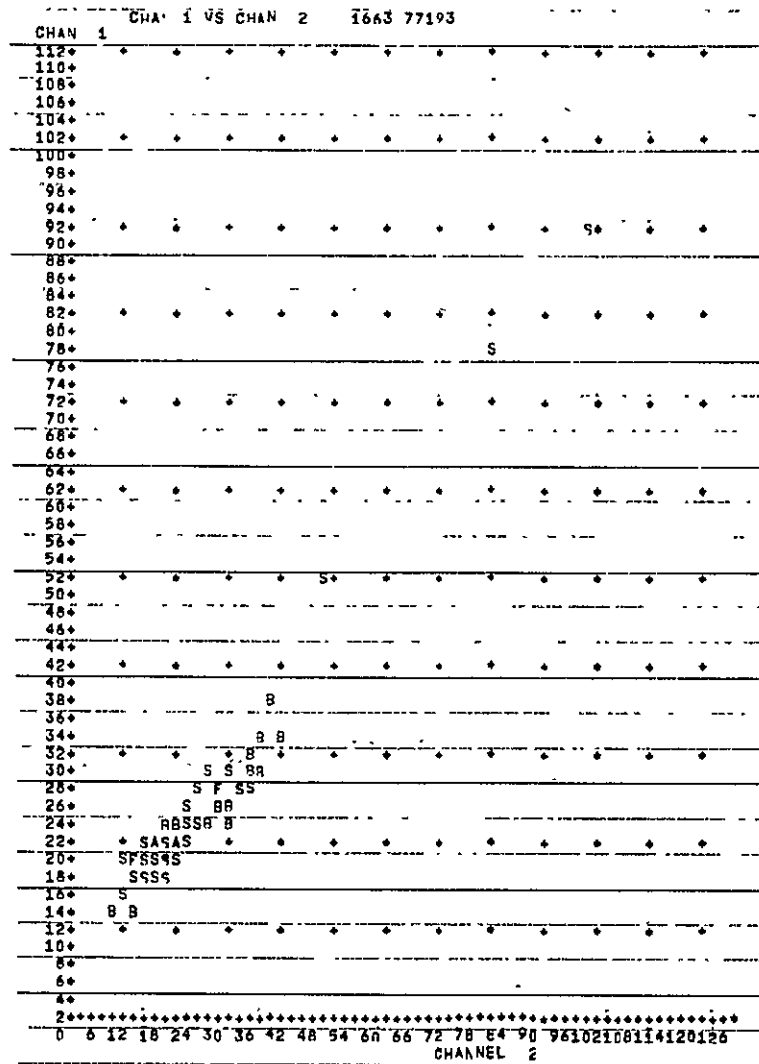
PLOT D-6.-- Concluded

(f) Brightness versus nominal Robertson scale -- crop plot for oats



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PLOT D-7.— RADIANCE VALUES FOR GROUND-TRUTH LABELS



Note: This scatter plot is provided for each acquisition. Six different graphs can be plotted:

- Channel 1 versus channel 2
- Channel 1 versus channel 3
- Channel 1 versus channel 4
- Channel 2 versus channel 3
- Channel 2 versus channel 4
- Channel 3 versus channel 4

Channels 1, 2, and 3 have a scale of 0 to 128; one space represents two radiance values. Channel 4 has a scale of 0 to 64; one space represents one radiance value.

Data representation: Data points are represented by the letter of the last hit.

Listings: Three listings of data are provided for each plot: a listing of multiple hits, a listing of the mean and standard deviation for each acquisition date, and a listing of the median for each crop and for each acquisition date.

PLOT D-7.— Continued

(a) Multiple hits listing

CHAN= 2	CHAN= 4	LINE/PIXI	* GND TRUTH
SEGMENT, ACO-- 1663	77193		
21	18	1/ 3	S
19	18	1/ 4	S
19	15	1/13	S
28	18	2/ 6	E
19	15	2/14	E
21	15	3/ 3	E
19	21	3/ 4	S
19	18	3/ 7	S
21	15	3/10	E
22	16	3/15	E
32	18	4/14	E
18	19	5/11	S
21	16	5/15	A
15	20	6/ 2	S
28	18	6/12	S
15	25	6/14	S
21	16	7/ 1	S
19	21	7/ 4	S
15	25	7/ 7	S
21	18	7/11	S
19	19	7/17	S
22	16	7/15	S
30	24	8/ 3	S
21	15	8/13	A
15	25	8/14	S
18	19	8/17	S
15	20	9/ 0	S
19	21	9/13	S
19	19	10/ 2	S
32	18	10/ 8	E
19	18	10/16	S
30	24	11/14	S

*THESE COUNTS ARE MULTIPLIED BY 10 FOR THE PLOT.

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PLOT D-7.- Continued

(b) Mean and standard deviation listing

SNO.	ACO.		W. WHEAT		BARLEY		RYE		OATS		FLAX		SPRING WHEAT	
			MEAN	STD. DV.	MEAN	STD. DV.	MEAN	STD. DV.	MEAN	STD. DV.	MEAN	STD. DV.	MEAN	STD. DV.
1602	77125	BRIGHTNESS	0.0	0.0	58.7	7.3	0.0	0.0	58.4	10.7	75.3	4.9	59.7	2.6
		GREEN NO.	0.0	0.0	3.9	1.0	0.0	0.0	4.6	2.8	0.0	1.7	4.2	2.4
		DET. COUNTS			9.	3.		0.	11.		3.		69.	
1602	77143	BRIGHTNESS	0.0	0.0	73.1	5.4	0.0	0.0	74.7	5.1	69.7	8.8	74.1	7.2
		GREEN NO.	0.0	0.0	4.0	3.8	0.0	0.0	4.1	4.4	1.5	1.5	3.0	4.9
		DET. COUNTS			0.	2.		0.	11.		3.		69.	
1602	77172	BRIGHTNESS	0.0	0.0	72.5	7.6	0.0	0.0	60.3	16.3	60.1	31.7	67.4	17.5
		GREEN NO.	0.0	0.0	31.7	14.6	0.0	0.0	23.9	13.2	6.8	5.7	24.1	13.4
		DET. COUNTS			0.	5.		0.	11.		3.		69.	
1602	77198	BRIGHTNESS	0.0	0.0	64.4	6.9	0.0	0.0	58.7	2.6	65.4	2.4	57.8	5.3
		GREEN NO.	0.0	0.0	30.3	7.4	0.0	0.0	23.5	8.3	18.5	16.6	24.3	7.0
		DET. COUNTS			0.	5.		0.	11.		3.		69.	
1625	77125	BRIGHTNESS	0.0	0.0	55.5	0.0	0.0	0.0	63.4	8.0	0.0	0.0	60.2	7.1
		GREEN NO.	0.0	0.0	4.1	0.0	0.0	0.0	5.2	7.4	0.0	0.0	1.9	3.3
		DET. COUNTS			0.	1.		0.	14.		0.		36.	
1625	77172	BRIGHTNESS	0.0	0.0	63.4	0.0	0.0	0.0	72.3	6.3	0.0	0.0	69.0	14.1
		GREEN NO.	0.0	0.0	28.7	0.0	0.0	0.0	18.6	6.1	0.0	0.0	17.6	8.9
		DET. COUNTS			0.	1.		0.	14.		0.		36.	
1625	77233	BRIGHTNESS	0.0	0.0	85.3	0.0	0.0	0.0	71.5	7.6	0.0	0.0	78.9	10.3
		GREEN NO.	0.0	0.0	7.5	0.0	0.0	0.0	4.3	3.7	0.0	0.0	1.7	2.4
		DET. COUNTS			0.	1.		0.	14.		0.		36.	
1637	77140	BRIGHTNESS	0.0	0.0	60.7	7.3	0.0	0.0	71.7	5.4	53.1	1.4	60.6	9.1
		GREEN NO.	0.0	0.0	6.5	7.3	0.0	0.0	13.4	7.9	3.3	0.3	5.8	5.6
		DET. COUNTS			0.	8.		0.	8.		2.		62.	
1637	77194	BRIGHTNESS	0.0	0.0	70.2	7.3	0.0	0.0	67.8	9.6	67.9	1.6	64.1	7.7
		GREEN NO.	0.0	0.0	25.0	10.5	0.0	0.0	22.4	3.5	33.5	3.2	26.1	7.0
		DET. COUNTS			0.	8.		0.	8.		2.		62.	
1637	77240	BRIGHTNESS	0.0	0.0	43.7	5.1	0.0	0.0	43.0	2.4	39.4	3.6	43.7	4.5
		GREEN NO.	0.0	0.0	5.0	3.7	0.0	0.0	5.0	4.9	2.2	0.2	4.0	3.4
		DET. COUNTS			0.	8.		0.	8.		2.		62.	

PLOT D-7.— Concluded

(c) Median listing

MEDIAN TABLE								
SEG.	ACQ.	CROP	NUMBER OF DOTS	BRIGHTNESS				
				LOWEST VALUE	25% VALUE	MEDIAN VALUE	75% VALUE	HIGHEST VALUE
1604	77125	W. WHEAT	0	0.0	0.0	0.0	0.0	0.0
		BARLEY	18	25.9	32.3	37.7	49.8	64.8
		RYE	0	0.0	0.0	0.0	0.0	0.0
		WATS	41	31.1	42.7	51.5	59.3	85.1
		FLAX	6	29.7	29.7	54.0	64.0	75.4
		S. WHEAT	60	26.5	33.7	40.6	46.6	70.8
GREEN NUMBER								
SEG.	ACQ.	CROP	NUMBER OF DOTS	BRIGHTNESS				
				LOWEST VALUE	25% VALUE	MEDIAN VALUE	75% VALUE	HIGHEST VALUE
1604	77125	W. WHEAT	0	0.0	0.0	0.0	0.0	0.0
		BARLEY	18	12.8	13.9	14.5	15.1	17.6
		RYE	0	0.0	0.0	0.0	0.0	0.0
		WATS	41	10.2	12.5	13.7	15.2	21.0
		FLAX	6	12.7	12.7	14.0	14.0	14.5
		S. WHEAT	60	11.2	13.0	13.9	15.0	22.1
BRIGHTNESS								
SEG.	ACQ.	CROP	NUMBER OF DOTS	BRIGHTNESS				
				LOWEST VALUE	25% VALUE	MEDIAN VALUE	75% VALUE	HIGHEST VALUE
1604	77143	W. WHEAT	0	0.0	0.0	0.0	0.0	0.0
		BARLEY	18	60.0	65.3	68.8	73.1	75.9
		RYE	0	0.0	0.0	0.0	0.0	0.0
		WATS	41	52.0	67.9	71.8	78.2	82.6
		FLAX	6	64.0	64.0	66.3	66.3	85.2
		S. WHEAT	60	47.9	64.0	68.2	71.9	81.3
GREEN NUMBER								
SEG.	ACQ.	CROP	NUMBER OF DOTS	BRIGHTNESS				
				LOWEST VALUE	25% VALUE	MEDIAN VALUE	75% VALUE	HIGHEST VALUE
1604	77143	W. WHEAT	0	0.0	0.0	0.0	0.0	0.0
		BARLEY	18	12.6	17.5	20.3	21.7	36.3
		RYE	0	0.0	0.0	0.0	0.0	0.0
		WATS	41	12.8	14.6	16.9	19.2	37.4
		FLAX	6	13.8	13.2	15.5	15.5	17.5
		S. WHEAT	60	11.1	15.3	17.4	20.6	28.3

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OF POOR QUALITY